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CALCULATION OF THE YEARLY ENERGY PERFORMANCE OF HEATING SYSTEMS BASED ON THE EUROPEAN BUILDING ENERGY DIRECTIVE AND RELATED CEN STANDARDS

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SUMMARY

In 2003 the European Commission (EC) issued a directive, 2002/91/EC [1]. The objective of this directive is to promote the improvement of the energy performance of buildings within the community, taking into account outdoor climatic and local conditions, as well as indoor climate requirements and cost-effectiveness. For new and existing buildings this requires a calculation of the energy performance of the building including heating, ventilation, cooling and lighting systems, based on primary energy. Each building must have an energy certificate and regular inspections of heating, cooling and ventilation systems must be performed. The present paper will present the method for calculating the energy performance for heating systems. The relevant CEN-standards are presented and a sample calculation of energy performance is made for a small family house in different geographical locations: Stockholm, Brussels, and Venice.

KEYWORDS

Energy performance of buildings, Building energy calculations, Standards.

INTRODUCTION

In 2003 the European Commission (EC) issued a directive, 2002/91/EC [1]. The objective of this directive is to promote the improvement of the energy performance of buildings within the community, taking into account outdoor climatic and local conditions, as well as indoor climate requirements and cost-effectiveness. For new and existing buildings this requires a calculation of the energy performance of the building including heating, ventilation, cooling and lighting systems, based on primary energy. Each building must have an energy certificate and regular inspections of heating, cooling and ventilation systems must be performed. The present paper will present the method for calculating the energy performance for heating systems. The relevant CEN-standards are presented and a sample calculation of energy performance is made for a small family house in different geographical locations: Stockholm, Brussels, and Venice.

CONCEPT OF THE EPBD-STANDARDS

This series of standards (about 40) have all been accepted as EN standards. The objective is to establish common calculation methods in Europe for energy performance of buildings and HVAC systems. Unfortunately this did not happened because the standardization work started too late and several countries have adopted national calculation methods. Also some of the standards do include alternative methods, which mean the energy performance of the same system may be evaluated differently in different countries.

Energy performance of heating systems

A basic standard for the calculation of the building energy demand (EN ISO 13790 [2]) will form the

central point of the calculation procedure. To perform this calculation, input data for indoor climate requirements, internal loads, building properties and climatic conditions are needed. Standards and methods for these input data exist already to a great extent. The calculation of the building energy demand does not take into account the heating-cooling-ventilation system. The calculated building energy demand serves then as an input to the calculation of the system energy requirement.
The boundary between building and system is shown in Figure 1 for a heating system. The additional losses are calculated for heat emission, distribution, storage and generation. The auxiliary electrical energy needed for fans, pumps etc. will also be calculated.
The effect of the control system is included in the building energy demand as well as the additional losses from the system due to sub-optimal control. The additional energy savings obtained with a whole building automation system (heating, cooling, ventilation, electrical appliances, light etc.) will be taken into account in a separate standard (EN 15232 [3]).
Output from the calculation (Figure 1) will be the net energy (building energy demand) together with the required heating/cooling ventilation energy for the HVAC systems, including the auxiliary energy. Finally, the total delivered energy for the building/system can be calculated by adding the required energy for all the systems, including lighting. This will be converted to Primary Energy, taking into account renewable energy sources and national conversion factors. The calculation process comprises three basic points, which are, calculation of net energy (building energy demand), calculation of delivered energy (system energy demand), and conversion to primary energy. Delivered energy takes into account the losses coming from the heat emission, heat distribution and heat generation system.

Heat losses for the heat emission system

Emission losses are due to three factors, namely, non-uniform temperature distribution, losses to the outside from embedded heating devices in the structure, and losses due to non-perfect control of the indoor temperature (EN15316-2.1 [5]). The heat energy losses of heat emission are calculated as

$$Q_{em,ls} = Q_{em,str} + Q_{em,emb} + Q_{em,ctr} \quad [J] \quad (1)$$

where:
$Q_{em,str}$ heat loss due to non-uniform temperature distribution in Joule (J);
$Q_{em,emb}$ heat loss due to emitter position (e.g. embedded) in Joule (J);
$Q_{em,ctr}$ heat loss due to control of indoor temperature in Joule (J).

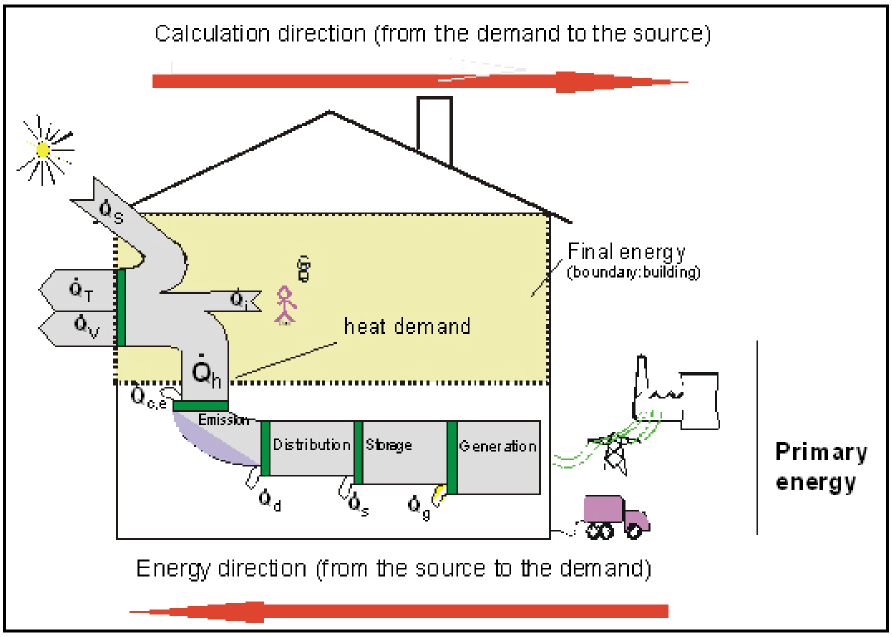

Figure 1. Calculation concept and building-system boundaries for heating (EN15316-1 [4])

Two methods are recommended in the standard. The two methods do not give exactly the same results, but the same trend. The two methods shall not be mixed. The present paper deals only with one of the methods.

The evaluation of $Q_{\mathrm{em,ls}}$ takes place monthly or by another time period in accordance with equation (2).

$$Q_{\mathrm{em,ls}} = \left(\frac{f_{\mathrm{Radiant}}\, f_{\mathrm{int}}\, f_{\mathrm{hydr}}}{\eta_{\mathrm{em,ls}}} - 1 \right) Q_{\mathrm{H}} \qquad (2)$$

where

$Q_{\mathrm{em,ls}}$ is the additional loss of the heat emission (time period), in kWh;
Q_{H} is the net heating energy (time period) (EN ISO 13790), in kWh;
f_{hydr} is the factor for the hydraulic equilibrium.
f_{im} is the factor for intermittent operation (as intermittent operation is to be understood the time-dependent option for temperature reduction for each individual room space);
f_{rad} is the factor for the radiation effect (only relevant for radiant heating systems);
η_{em} is the total efficiency level for the heat emission in the room space.

The total efficiency level is fundamentally evaluated as

$$\eta_{em} = \frac{1}{(4 - (\eta_{str} + \eta_{ctr} + \eta_{emb}))} \qquad (3)$$

where

η_{str} is the part efficiency level for a vertical air temperature profile;
η_{ctr} is the part efficiency level for room temperature control regulation;
η_{emb} is the part efficiency level for specific losses of the external components (embedded systems). In individual application cases this breakdown is not required. The annual expenditure for the heat emission in the room space is calculated as

$$Q_{\mathrm{em,ls,a}} = \sum Q_{\mathrm{em,ls}} \qquad (4)$$

where

$Q_{\mathrm{em,ls,a}}$ is the annual loss of the heat emission, in kWh;
$Q_{\mathrm{em,ls}}$ is the loss of the heat emission (in the time period) in accordance with equation (2), in kWh.

Default values for the different efficiencies and factors can be found in an informative annex to the standard. Some of these values are based on real data from experiments and/or computer simulations, while others are made by agreement. Examples of the values included in the annexes are given in table 2.

Heat losses for the heat distribution system

The heat losses of a distribution system depend on the average temperature of the heating medium, the temperature of the surrounding envelope, length and insulation of the pipes EN15216-2.3 [6]) .
For the heat losses in a time step the following formula applies:

$$Q_D = \sum_i U' \cdot (\vartheta_m - \vartheta_a) \cdot L \cdot t_H \quad [\mathrm{J}] \qquad (7)$$

where

U' U-value per length, [W/mK]
ϑ_m average medium temperature, [°C]

ϑ_a surrounding temperature, [°C]
L length of the pipe [m]
t_H heating hours in the time step, [h]

The standard gives three methods of calculation:
A detailed method according to the above general equation gives the most exact values. Detailed input values from the design documents are needed.
The standard includes a simplified method where only a few input data are needed. For example the length of pipes is calculated by approximations depending on the outer dimensions of a building. With this method the calculated energy losses are higher than calculated by the detailed method.
A tabulated method based on the simplified method with even further approximations is also included.
The calculation method for the electrical energy demand of pumps has two parts. The first is to calculate the hydraulic conditions of the distribution system and the second is to calculate the energy expenditure factor of the pump. For this part it is possible to mix the detailed method with the simplified method. For example the calculation of pressure loss and mass flow can be calculated by the detailed method and the expenditure energy factor may be calculated by the simplified method or vice versa. The calculation method can be done for any time period (day, month, or year). For details concerning the calculations reference is made to standard.

Heat losses for the heat generation system

To calculate the losses from the generation system only boilers (EN15316-4.1 [7]) are considered in this paper. Separate standards exist for other heat generating systems like heat pumps, CHP, district heating, solar heating and biomass combustion systems. For boilers, two types of calculation method are included in the standard: Typology method and Case-specific method.
The typology method considers the calculation period as the heating season. The calculation is based on data related to the boiler directive. The operation conditions, taking into account climate, distribution system connected to the generator, etc., are approximated by typology of the considered region and are not case-specific. If this method is to be applied, an appropriate national annex with the relevant values shall be available. The method is applicable only to boilers for which the full load and the 30% part load efficiency values according to the boiler directive are available. These are net efficiency values (highest efficiency values, referenced to the lower heat value of fuels). It is essential that both test results are available and that the tests are appropriate to the type of boiler as defined in the directive, otherwise the calculation cannot proceed. In the procedure, the data are first converted to gross efficiency (lower efficiency values, referenced to the higher heat value of fuels) under test conditions, and then converted to a seasonal efficiency that applies under typical conditions of use in a dwelling.
The case-specific method is also based on the data related to the boiler directive, but supplementary data are needed in order to take into account the specific operation conditions of the individual installation. The considered calculation period can be the heating season but may also be a shorter period (month, week, or the operation periods according to EN ISO 13790). The method is not limited and can be used with the default values given in an informative annex B in the standard.
This method is related to the European Boiler Directive. It is based on expressing the losses for three different load ratios or power outputs at 100% load, intermediate load and 0% load.
The calculation of the losses for a specific load, is obtained by linear interpolation between these three power outputs. Efficiency for oil and gas-fired boilers measured is according to the boiler directive at full load with an average boiler water temperature of 70° C. This efficiency has to be corrected in accordance with the operating temperature of the individual installation.
The third method distinguishes more explicitly the losses of a generator that occur during boiler cycling (i.e. combustion losses). Some of the parameters can be measured on site. This method is adapted for existing buildings.

RESULTS

The calculation method was used for a small one-family house with a floor area of 101 m^2 (Figure 2).

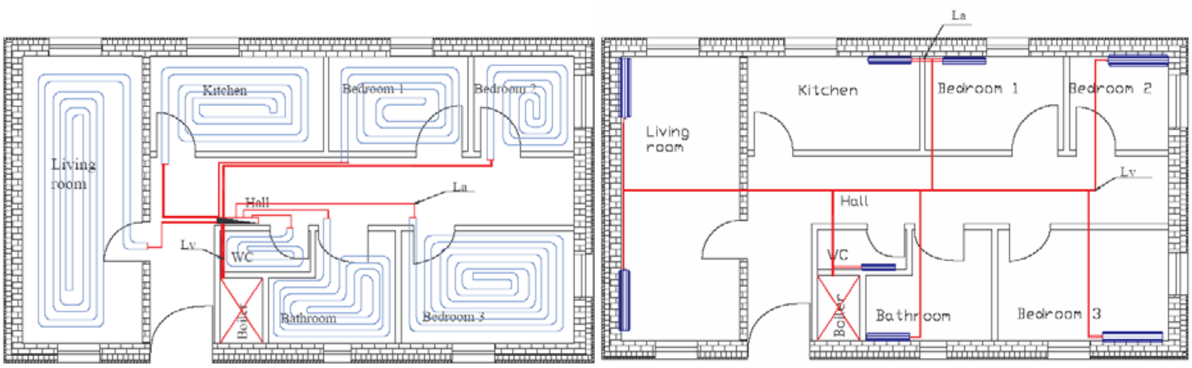

Figure 2. Layout of house with floor heating and radiator heating.

Net energy calculation

First of all the net energy (building energy demand) was calculated according to EN13790 for the building located in three different climatic zones: Stockholm, Brussels, and Venice. Table 1 show the results together with values for the design heat load, design outdoor temperature and heating season average outdoor temperature.

Table 1. Net energy data for a residential building used in the calculations (EN13790).

			Climatic zone		
Location			Stockholm	Brussels	Venice
Design outdoor temperature,		ºC	-16	-10	-5
Average heating season outdoor temperature		ºC	3.3	6.6	7.8
Residential	Design heat load	W/m^2	54	45	38
	Yearly net energy demand	Wh/m^2	142	88	66
	Domestic Hot Water	Wh/m^2	22	22	22

Emission losses

Losses due to emission from radiators and floor heating systems are calculated for all climatic conditions. The building heat energy requirements Q_H, calculated for each situation based on EN 13790, is used in the calculation of the emission losses.
The emission losses are only calculated after one of the methods in EN15316-2-1 [5].
Emission losses are calculated for different control systems and different system water temperatures. Table 2 gives the results and description of the system types.

Delivered primary energy calculations

The following table is based on the overall primary energy calculations. A building generally uses more than one type of energy ware (e.g. gas and electricity). The primary energy approach makes possible the simple addition from different types of energies (e.g. thermal and electrical) because this approach integrate the losses of the whole energy chain.

Table 2 Calculation of heat emission losses in a residential building

Residential building		ΔT °C	η_{str1}	η_{str2}	η_{emb}	η_{ctr}	η_{str}	$\boldsymbol{\eta_{em}}$	Stockholm $Q_{em,ls}$	Brussels $Q_{em,ls}$	Venice $Q_{em,ls}$
									Q_H = 141.85	Q_H = 87.55	Q_H = 66.42
									KWh/m²	KWh/m²	KWh/m²
Radiators (Boiler) 70/55/20	P(2K)	42.5	0.93	0.95	1	0.93	0.94	**0.88**	18.4	11.4	8.6
	P(1K)					0.95		**0.90**	15.6	9.6	7.3
	PI					0.97		**0.92**	12.8	7.9	6.0
Radiators (Boiler) 55/45/20	P (2K)	30	0.95	0.95	1	0.93	0.95	**0.89**	17.0	10.5	8.0
	P (1K)					0.95		**0.91**	14.2	8.8	6.6
	PI					0.97		**0.93**	11.3	7.0	5.3
Radiators (Heat Pump) 50/35/20	P (2K)	22.5	0.96	0.95	1	0.93	0.955	**0.90**	16.3	10.1	7.6
	P (1K)					0.95		**0.91**	13.5	8.3	6.3
	PI					0.97		**0.93**	10.6	6.6	5.0
			η_{emb1}	η_{emb2}	η_{emb}	η_{ctr}	η_{str}	$\boldsymbol{\eta_{em}}$			
Floor heating 35/28	P-control		0.93	0.95	0.94	0.93	**1**	**0.89**	18.4	11.4	8.6
	PI-control					0.95	**1**	**0.90**	15.6	9.6	7.3
Floor heating extra insulation	P-control		0.93	0.99	0.96	0.93	1	**0.90**	15.6	9.6	7.3
	PI-control					0.95		**0.92**	12.8	7.9	6.0
Floor heating No downwards loss	P-control		1	1	1	0.93	1	**0.93**	9.9	6.1	4.6
	PI-control					0.95		**0.95**	7.1	4.4	3.3

$Q_{em,ls}$ is the additional loss of the heat emission (time period), in kWh;

Q_H is the net heating energy (time period) (EN ISO 13790), in kWh;

η_{em} is the total efficiency level for the heat emission in the room space;

η_{str} is the part efficiency level for a vertical air temperature profile;

η_{ctr} is the part efficiency level for room temperature control regulation;

η_{emb} is the part efficiency level for specific losses of the external components (embedded systems).

Therefore the primary energy consumption may be used for comparison of different types of energy systems.

The conversion factors are listed on the national level. The standard includes default values suggested as primary energy factors. The energy used for different purpose and by different fuels is recorded separately. For natural gas the conversion factor is f_P= 1.1, electrical power is converted by factor f_P=2.5.

The results of primary energy consumptions are presented in table 3 for the residential building in Brussels. The additional losses from the heating systems are given as a %-value of the building energy demand (100%). The calculation for condensing boiler is made with the upper energy conversion factor, so the “heat generation losses” in many cases will be negative.

Table 3. Primary energy losses for heat emission, distribution and generation as % value of the building energy demand.

Residential building in Brussels Condensing boiler and regulated pumps	Building demand	Emission	Distribution		Generation		Total
			Heat	Aux.	Heat	Aux.	
Radiator 77/55 P(2) control,	100	14	5	3	-1	4	125
Radiator 77/55 P(1) control,	100	12	5	3	-1	4	123
Radiator 55/45 P(1) control,	100	11	4	4	-4	4	119
Floor heating 35/28 on/off PI control,	100	12	1	5	-8	4	114
Floor heating 35/28 on/off PI control, Increased insulation	100	10	1	5	-8	4	112
Floor heating 35/28 on/off PI control, No downward loss	100	5	1	5	-8	4	107

To illustrate the effect of other heat generators the following diagram (Figure 3) is presented:

- Standard wet floor system, 35/28 supply/return water temperature, On-Off control (PI),
- Radiator with Heat Pump, 50/35 supply/return water temperature, wall mounted PI-control
- Radiator with Boiler, 77/55 supply/return water temperature, wall mounted PI-control

The calculations are made for three different heat generators:

- Boiler condensing
- Air to Water heat pump (A-WHP)
- Ground source heat pump (GSHP)

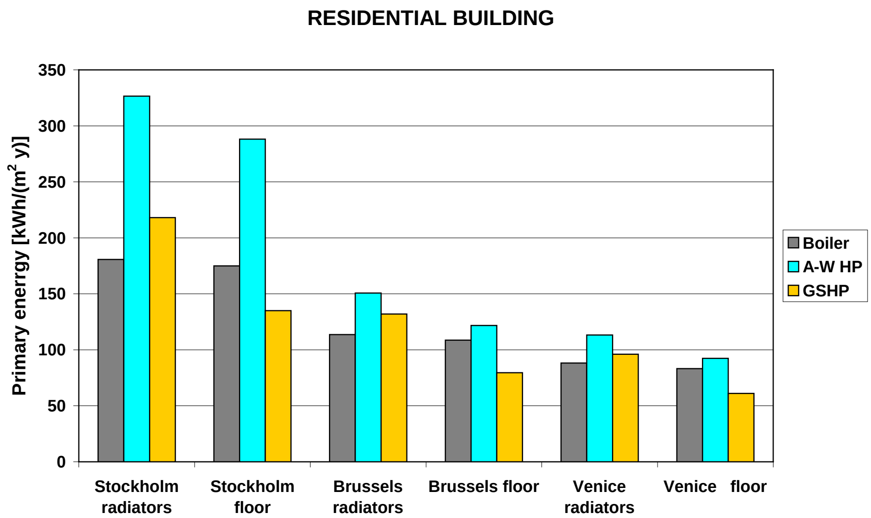

Figure 3. Primary energy calculations for the residential building, with three different heat generators and for three geographical locations.

DISCUSSION

Thermal and auxiliary energy required for the heat emission system was calculated according to four different approaches, which have been suggested by the European standard prEN15316-2.1. Two different types of system were studied: radiators and floor heating for two cases of temperature control.

For floor heating the most important factor is the downward heat loss (5%). This will be the case only for the ground floor and could be compensated for by increased insulation. This is, compared to radiators, somewhat compensated for by a more uniform temperature distribution. The energy efficiency of the control is similar for the two systems. In total the floor heating has then for a ground floor space slightly higher additional emission losses than the radiator.

The distribution losses depend very much on the temperature of the heating medium and whether the piping is in the heated zone, which means it could be recovered. In the present calculations a floor system with water temperatures of 35 ºC to 28 ºC is compared to a radiator system with a temperature range of 70 ºC to 55 ºC. This will result in higher thermal losses for the radiator system. On the other hand the auxiliary losses from the circulation pump are higher for the floor heating system due to the smaller difference between supply and return. If the radiators work with a lower temperature range (55 ºC to 45 ºC) the thermal losses will be reduced, but the auxiliary losses will increase. The thermal losses are, however, more significant. Some of these thermal losses may be recovered for the pipe sections within the heated space. The most advanced method for taking this into account would be to re-calculate the net-energy for the building (EN13790), including the recoverable thermal losses from the distribution system in the internal heat loads. Especially for floor heating it is recommended to use an electronic pump to reduce the auxiliary losses. In the standard for distribution losses (EN15316-2.3) an even more detailed method may be used.

For the overall primary energy consumption the low temperature heating system, floor heating, is he most efficient.

CONCLUSIONS

The present study shows that the losses of a heating system will add 7-25 % to the net-energy for the building. The additional losses are different for different emission systems. Embedded systems like floor heating will, for the ground floor, have higher downward losses. An emission system with a higher water temperature like radiators, will have higher losses in the distribution and generation system.

The auxiliary losses for circulation pumps and generators are small compared to the thermal losses.

A low temperature heating system like floor heating has in all cases the best overall energy performance.

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